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A Proposal to Perform New Theoretical and Experimental Research on Human Efficiency Through Developments Within Systems Factorial Technology (SFT)

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Project is complete. A model of configural processing in which humans process global characteristics (such as general shape) first and then local characteristics (like the fine details of a pattern) is presented. The Blobloc model is a culmination of findings within the GRT and SFT methods and serves to connect physiologically plausible processing mechanisms with perception modeling. It can be adapted to account for learning effects. An experiment to test the model has been designed using sinusoidal grating patterns that vary in contrast in a single direction. The parameters of Blobloc allows for the direct comparison of feature-by-feature processing versus holistic/ or configural processing mechanisms by the human.

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Abstract

The researchers developed a model of configural processing in which humans process global characteristics (such as general shape) first and then local characteristics (like the fine details of a pattern). The Blobloc model is a culmination of findings within the GRT and SFT methods and serves to connect physiologically plausible processing mechanisms with perception modelling. The model has the capability to provide a basis for configural processing phenomena and can be adapted to account for learning effects. The researchers have equipped the Blobloc model with dynamic accrual processes so that we can make reaction time predictions as well as confusions. An experiment to test the model has been designed using sinusoidal grating patterns that vary in contrast in a single direction. These stimuli are designed to provide optimal firing rates for simple neurons located in V1. The parameters of Blobloc allows for the direct comparison of feature-by-feature processing versus holistic/ or configural processing mechanisms by the human. In addition, in the experiments intended to investigate the potential for identifying violations of decisional separability, running all proposed paradigms, the complete identification paradigm and the double-factorial paradigm, in two conditions involving the manipulation of response payoffs, one intended to reward unbiased responding and the other intended to reward biased responding toward specific subsets of the stimuli, researchers successfully demonstrated the ability to induce stable shifts in response bias. Specifically, they demonstrated this ability with stimuli that, in previous work, have been shown to be composed of either integral or separable dimensions.

ORIGINAL OBJECTIVES

In the original proposal, there were three objectives to be achieved concurrently. The first was the development of theoretical foundations for fundamental aspects of human information processing that goes beyond specifying models and instead allows the universal testing of a broad band of critical questions. The second thrust includes a series of experiments to exploit theoretical advances of the first objective to catalog and assess holistic human processing versus component-wise processing. Dr. Townsend's lab has invented statistical tests for human data that are pertinent in determining the validity of particular information processing notions. The third objective was to create software toolboxes for the implementation of these statistical tests on various platforms. These objectives were met, while new and important projects grew from the seminal goals.

Meta-theory

Selective Influence and Perceptual Separability. We have begun developing mathematical definitions regarding the concept of 'selective influence' in systems when both accuracy as well as reaction time (RT) are analyzed. We conducted detailed analytic investigation on the properties of 'selective influence' based on two most developed sequential sampling models, the Wiener diffusion model and the Poisson Race model. We found that both models predict the same RT and accuracy changes on correct responses. However, our results indicate that under certain conditions, the two classes of models may predict different patterns of errors. This line of research reveals the fundamentals of how subjects may respond to changes of salience and it is critical to the research team's work on ARTSFT (Accuracy and Response Time SFT).

The research team's two most important theoretical developments over the past several decades have been Systems Factorial Technology (Townsend & Nozawa, 1995), which is founded on the assumption of selective influence and General Recognition Theory (Ashby & Townsend, 1986) which tests, among other issues, perceptual separability of dimensions (or features). Some of our most contemporary theoretical efforts have been devoted to exploring the deep similarities and distinctions between these two critical conceptions. A new paper has been submitted for publication based on these results (Townsend, Liu & Zhang, 2017).

ARTSFT. A major aspect of generalizing the RT-only SFT to ARTSFT involves extending our SIC (Survivor Interaction Contrast) function to encompass accuracy as well. The research team has discussed the new SIC measure, and the development of the mathematical models and relative theorems is still underway. This new measure provides more powerful information for assessing the characteristic (i.e., mental architecture and stopping rule) underlying information processing theorems. The meta-theoretical work has been performed primarily by former student Dr. Haiyuan Yang and her recently-completed Ph.D. thesis presented these powerful new theorems as well as simulations and a preliminary application to some previously collected data (Yang, 2016).

Experiment. In line with the theoretical work on selective influence and ARTSFT, we conducted a low-accuracy perception experiment employing the double factorial paradigm. Data collection was completed during the summer of 2016 and analyses are almost finished. Preliminary analysis on RT has revealed patterns that cannot be explained by the diffusion model. The new ARTSIC (Accuracy and Response Time SIC) measure has also been applied, and the SIC signatures suggest that all subjects were using the proper exhaustive stopping rule, but some subjects used a serial processing strategy while others were using parallel processors. This finding is consistent with the results of Fific, Nosofsky & Townsend (2008).

Configural Perception and Learning Experiments

Configural Superiority. Our research has focused on the phenomenon of configural superiority, employing our capacity measures, with their proven quantitative precision. Specifically, the team has been working on an experiment that attempted to separate the effects of perceptual and decisional separability. This work was done primarily by Assistant Professor and former graduate student, Devin Burns, and visiting undergraduate honors student Ms. Aleina Wachtel.

Experiment. One of the greatest criticisms of static GRT (accuracy only, no reaction times) is its inability to empirically distinguish perceptual and decisional separability, as detailed by Silbert and Thomas (2012). In hopes that RTGRT will be more capable of such a distinction, the team designed an experiment to manipulate those two forms of independence in a full factorial manner; Ms. Yanjun Liu (graduate student) conducted 4 experiments in which all combinations of perceptual independence/dependence and decisional independence/dependence should be present. The perceptual side was manipulated by the choice of stimulus dimensions, using either separable (line position and color saturation) or integral (color saturation and color brightness) dimensions.

Different groups of subjects used either stimulus set. Each group then participated in two types of conditions designed to support or erode decisional separability based on payoffs. The neutral payoff condition encouraged bounds parallel to the axis, but a correlated payoff structure, where the top left and bottom right responses (for example) are favored to the other two, was used to encourage diagonal bounds.

The perceptual distributions in these two conditions should remain constant, since the stimuli are the same. The goal was to fit a GRT model using the stimulus parameters from the unbiased condition, thus only needing to fit the free parameters corresponding to the decision bounds. However, this was not possible given the particular recalibration of equipment and stimulus levels for each subject during each session. After a preliminary investigation of the experiment with height and width of rectangular stimuli compared with data from arc-length and orientation of radial stimuli, we found that rectangular stimuli (thought to be perceptually integral) tended to violate perceptual separability with a parallel exhaustive model. The radial stimuli (thought to be perceptually separable) were best described by a perceptually separable model with serial architecture and exhaustive stopping rule. Thus, they have converging evidence that not only are these stimuli ideal for studying perceptual dependence questions, but that statistical results from the Reaction Time General Recognition model are consistent with General Recognition Theory statistics.

We further extended previous experiments on the perceptual interactions between the dimensions of skin color and face shape in racial categorization judgments. Mr. Brett Jefferson (graduate student) and Ms. Meelia Palakal (senior undergraduate student) worked on modeling human perception of face stimuli. As noted above, Systems Factorial Technology is a technique for validating and rejecting model characteristics (Townsend & Nozawa, 1995). Some characteristics include architecture (parallel processing models versus serial processing models), stopping rule (process all factors vs. processing some subset of factors), independence (stochastic independence of processing dimensions), and workload capacity (resource limitations of a processing system). This modeling approach has shown success with features of face stimuli (Wenger & Townsend, 2006), however, ethnicity perception has not been investigated using Systems Factorial Technology. Previously, graduate students Devin Burns and Brett Jefferson ran a preliminary study to examine changes in processing models of race with changes in attention demands. In that within subjects study, three categorization tasks systematically called subjects' attention to either skin tint, physiognomy, or both.

Although the results support some consistency across attention, the stimuli appear not to satisfy a fundamental assumption of the modeling procedure, selective influence. In 2015, they ran many more trials of one condition of that study (the control condition, in which stimuli only change in the dimension relevant to make decisions). Unlike the previous study, the investigators focus on effect size modulation related to selective influence. In addition, of particular interest to the researchers was the Survivor Interaction Contrast function (a byproduct of Systems Factorial Technology). If subjects only attended to the relevant dimension we'd expect a serial, self-terminating result. However, while most subjects showed interaction effects with the irrelevant change in the stimulus, there were three subjects who also produced non-serial self-terminating results. This result confirms the non-independence of skin tint and physiognomy.

Simulations. Currently, there still exists a question about the role of decision bounds in Systems Factorial Technology. Some evidence accumulation models have provided a reasonable account of identification and speeded classification experiment data (Ashby et. al., 1994; Ashby & Maddox, 1992; Maddox & Ashby 1996, Birnbaum 1998). Given that ability to explain accuracy

data, the researchers believe that they also have the ability to explain deviations in Survivor Interaction Contrast Functions (see above paragraph) from what would otherwise be predicted from standard parallel, serial, or coactive models. Undergraduate researcher, Mr. Cheng Shi re-examined the data from Burns and Jefferson's above study using the classic spatial modeling procedure Multidimensional Scaling. The preliminary analysis suggests that subjects' perceptual organization of the face stimuli is ordinal as expected. However, subjects may be using non-linear decision bounds to separate the faces into their respective experimental categories. Under the guidance of graduate student Brett Jefferson, Mr. Shi ran simulations to see how this non-linearity can produce deviations from standard Survivor Interaction Contrast functions.

In addition, doctoral candidate Ms. Yanjun Liu investigated theoretical work regarding decisional bounds that represent the above types of decisional bias within the context of certain assumptions concerning invariance of cross-stimulus covariance matrices. In a two-alternative classification task subjects are asked to make simple decisions on two stimuli. Assuming that performance on this task is based on sampling from two 2-dimensional Gaussian distributions (perception space representations of the two alternatives), our theoretical results showed that the slope of the discrimination function is a function of covariance matrices and means of Gaussian distributions. Under the assumption of invariance of covariance matrices with stimulus and linear decision bounds separating the stimuli, Liu showed that the manipulations in human bias can only effect the intercept of the decision bounds and not the slope. This important theoretical work reduces the number of parameters in the model and adds insight to larger body of perceptual modeling.

Another line of visual configurality experiments (with dots, following the work of James Pomerantz) continues. In previous work, the researchers used a mathematical measure of capacity to demonstrate that subjects performed a change-detection task more efficiently when local changes were accompanied by a change in configural properties, such as the orientation of an implicit line between two physically disconnected dots. Recently, the researchers supplemented these results with an additional experiment testing the processing of proximity as

an emergent feature, replicating the findings for orientation. Since these two features are the foundation for Professor Pomerantz's influential taxonomy of emergent features, the researchers believe this work provides a new process-level understanding of configural features. These experiments were developed by Robert Hawkins, a former undergraduate in our lab, and Dr. Joseph Houpt, assistant professor at Wright State University and former member of our lab. A paper has very recently appeared in Vision Research on our findings (Hawkins, Houpt, Eidels, & Townsend, 2016).

Experiment. Visual perception has a long history of using the Fourier Decomposition as a mathematically convenient, yet physiologically sound way to rigorously describe stimuli. This decomposition can be described as function over the three dimensions of frequency, phase, and orientation. Although much work has been done studying the dimensions singly (Graham 1989; Olzak & Thomas 1999; Saylor & Olzak 2006), little has been done in way of understanding how the dimensions interact with each other. In addition, subjects have shown the propensity for showing interdependencies with simple line stimuli (Townsend, Hu, & Kadlec 1988). Brett Jefferson (graduate student) will use methodology developed in the Townsend lab (Reaction Time General Recognition Theory) and dynamic systems to model interactions between frequency and orientation over time. This work will fill a much needed gap in the computational models of Fourier processing models. In two experiments, the researchers will first determine the appropriate spatial representation of simple sinusoidal gratings. In the second experiment the researchers will extend this model to account for stimulus integration by accounting for accurate identification and information integration (Nandy & Tjan, 2008) in compound sinusoidal gratings. These experiments will provide a test of the Blobloc model (Townsend, Hu, & Kadlec, 1988) which links performance of simple visual stimuli to more complex stimuli.

Computer Toolboxes

Mr. Robert Hawkins (a former undergraduate student in the Townsend Laboratory for Mathematical Psychology and presently a graduate psychology and cognitive science student at Stanford University) developed a toolbox for standard GRT (General Recognition Theory)

measures. Although GRT was first introduced as a theoretical framework by Townsend and Ashby in 1986, recent work (Mack, Richler, Gauthier, & Palmeri, 2011) has revealed serious problems with the inferential machinery needed to apply the framework to empirical data. In collaboration with Noah Silbert, the researchers implemented recent recommendations from Silbert and Thomas (2013), providing up-to-date statistical methods to conduct GRT analyses. Following the result that failures of decisional separability are not identifiable, the researchers focused on testing perceptual separability and independence, providing the following options: 1) full Guassian model fitting, with visualization; 2) factorial tests of marginal response invariance to detect failures of perceptual separability; and 3) test of sampling independence to detect failures of perceptual independence. All of these objectives have been met, with the further addition of some 'advanced' features to provide GRT analyses for more sophisticated concurrent detection designs (Wickens, 1992). The toolbox is available for download through CRAN (http://cran.r-project.org/web/packages/mdsdt/index.html). We are currently preparing a GRT tutorial for publication, which introduces this toolbox for practical use.

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1. Townsend, J.T., Liu, Y. & Zhang, Ru (2017) Selective Influence and Classificatory Separability (Perceptual Separability) in Perception and Cognition: Similarities, Distinctions, and Synthesis. In D. R. Little, N. Altieri, M. Fific & C-T. Yang (Eds*.) Systems Factorial Technology: A Theory Driven Methodology for the Identification of Perceptual and Cognitive Mechanisms* (pp.93-114). San Diego, California: Academic Press.
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